Reducing Gonad Irradiation in Pediatric Diagnosis

HARRY A. BISHOP, M.D., MILO WEBBER, M.D., and
BERNARD J. O'LOUGHLIN, M.D., Ph.D., Los Angeles

• The greatest danger of carcinogenesis and of genetic damage through diagnostic radiologic procedures is in children, whose smaller bodies are more vulnerable and who have a longer life span in which this damage can be realized.

Film badges placed on the gonad area during radiologic studies indicated widely varying degrees of gonad irradiation from similar procedures. These results emphasize the importance of technique in protecting children from unnecessary exposure. Such exposure can be reduced by greater beam filtration, use of higher tube potentials, careful beam collimation and centering, closer coning and shielding of the gonads. A new film tested reduced exposure time by 50 per cent. Further reduction was obtained by high-speed screens.

A most important measure is avoidance of unnecessary, repetitious and undiagnostic studies.

Fluoroscopy should be avoided if possible. If not, the operator must dark-adapt his eyes, use the smallest possible current, the narrowest beam, and the shortest exposure time. Image intensification promotes these aims.

Modern equipment, properly shielded, assures against unsuspected exposure.

ALTHOUGH CLINICAL radiologic study causes no more radiation to our population than do natural sources, it is still by far the largest artificial cause of ionization of human genes. Every radiologic operator is responsible for the quantity of radiation he is adding to the background and for the hazards he thereby occasions. A review of current literature, as well as the authors' experience with radiation dose measurement, makes it evident that exposures for radiographic purposes are often greater than the minimum necessary to activate the intensifying or fluoroscopic screen—and this excess is greatest in studies of children.

There seems to be a growing tendency to resort to radiologic solution of almost every diagnostic problem in pediatrics.[6] Most pediatricians want a great number of films and many wish to have their fluoroscopic observations confirmed by a radiologist.[33] Many of the diagnostic procedures requested of radiologists are those that involve large exposures, such as cardiac catheterization, angiocardiography and cinematography.[8] Since children are difficult to position and immobilize and since the equipment used is designed primarily for adults, there is a tendency to irradiate relatively larger portions of the body of a child than in an equivalent examination of an adult.[18] It is not uncommon to see part of the head and much of the abdomen and even the pelvis on chest films of infants. Furthermore, all parts of a child's body are nearer to its gonads than are the corresponding parts in adults, and the gonads are more vulnerable to radiation in children than in adult patients. Children have a longer life expectancy in which to acquire a cumulative exposure, and there is some evidence that immature tissues may be especially sensitive to radiation damage.[10]

Gross tissue changes such as epilation and erythema are not caused by the exposure dosages ordinarily used in diagnostic radiography today, but the possible leukemogenic and genetic effects cannot be ignored. According to Lewis[14] there is no threshold absorbed dose for the induction of leukemia. By extrapolation of animal experimental data, Brues[5] raised many interesting questions about the possible effect of radiation on man with regard to leukemogenesis, aging and other somatic changes. Integral exposure dose seems to be related directly to leukemogenesis. Protective measures here would be especially rewarding. While genetic injury has not yet been demonstrated in man, there is abundant evidence from animal experiments that harmful mutations can result even from low exposure of the gonads to irradiation. Nor does there appear to be a threshold for the genetic effects of radiation; the damage is cumulative, permanent and inheritable. A summary of the evidence for somatic, genetic and carcinogenic effects of radiation in children may be found in a recent review by Robinow and Silverman.[25]

The chief concern, then, in reducing unnecessary irradiation in diagnostic radiology, is with children and especially with protecting the gonads. A number of measurements of gonad doses due to diagnostic x-ray procedures have been published.* Those dealing with children are summarized in Table 1. In comparison with the exposure data shown in the

Presented before the Section on Radiology at the 87th Annual Session of the California Medical Association, Los Angeles, April 27 to 30, 1958.

From the Department of Radiology, University of California at Los Angeles School of Medicine, Los Angeles.

*References 2, 3, 4, 9-17, 24, 27, 28, 31.

TABLE 1.—Gonad Area Exposure Doses in Diagnostic Radiography of Children (in milliroentgens)

	Age Group 0-2 Yr.		2-7 Yr.		7-11 Yr.	
Sex	M	F	M	F	M	F
Chest, posteroanterior[8]	0	2	0	0	0	0
Chest, posteroanterior[11]*	5	....	....	....	....	....
Chest, posteroanterior[31]†	....	....	0.2	0.06	3.3	3.3
Chest, lateral[31]	....	....	0.5	6.0	0.15	6.0
Skull, basal[8]	1	1	0	0	0	0
Skull, lateral[31]	....	....	0.01	0.025	0.006	0.02
Skull series[31]	....	....	....	....	0.4	0.25
Abdomen, anteroposterior[8]	150	....	310	130	250	240
Abdomen, anteroposterior[31]	....	....	82	46	240	95
Lumbar spine, lateral[8]	800	300	500	1200	300	730
Lumbar spine, lateral[31]	....	....	190	110	145	180
Lumbar spine series[31]	....	....	270	160	300	250
Pelvis, anteroposterior[8]	160	90	280	140	700	300
Pelvis, anteroposterior[31]	....	....	90	50	120	50
Hip, anteroposterior and lateral[31]	....	....	180	100	570	200
IVP[11]	500	300	1008	678	1520	1384
IVP[31]	....	....	330	180	1000	370
IVP[12]‡					654	706
Gastrointestinal series[11]	220	....	496	....	220	....
Gastrointestinal series[31]	....	....	32	96	50	185
Barium enema[11]	450	400	700	455	900	800
Barium enema[31]	....	....	36	96	64	220

*Reference 11: Measurements in phantoms of size corresponding to ages 3 mo., 3 yr. and 6 yr.
†Reference 31: Measurements in phantoms of size corresponding to ages 3 yr. and 10 yr.
‡Reference 12: Measurements in children.

table, the average gonad exposure from natural background radiation is in the neighborhood of 100 milliroentgens per year and the "doubling dose"—that is, the amount that would double the spontaneous mutation rate—is estimated to be in the range of 40,000 to 80,000 milliroentgens for humans.[20,22] The "permissible" occupational exposure is now set at 100 milliroentgens per week.

Purpose of Measurements

One purpose of making gonad dose measurements is to evaluate the genetically significant gonad exposure-dose (G_m) to a population from medical exposures to ionizing radiation. As defined by a study group[10] of the International Commission on Radiological Units and Measurements and the International Commission on Radiological Protection, this value, G_m, is the summation of the product of the average annual gonad dose D_i, received by each person in age group "i", multiplied by the child expectancy, P_i, of the age group, multiplied by the number of individuals N_i, in the age group, divided by the expected number of offspring of the population:

$$G_m = \frac{\Sigma D_i \; P_i \; N_i}{\Sigma \quad P_i \; N_i}$$

The international commissions can apply data collected by these and other measurements, with the demographical material above, to the solution of this problem.

STUDY OF EXPOSURE DOSAGE

Virtually all previous exposure-dose studies have been made on tissue-equivalent phantoms by means of air-chamber roentgen meters. At the UCLA Medical Center the authors attempted to measure the actual irradiation incurred by children through roentgenography. For seven weeks all children under the age of 12 years thus examined were badged with small sensitive dosimetry films. One film was attached to the skin where it would lie in the central beam; another was placed on the scrotum or near it or on the skin of the upper medial anterior thigh. (The films were attached according to prescribed method by the technician making the exposures.) The films were calibrated against a standard (Victoreen 250-milliroentgen) ionization chamber with approximately the same quality of radiation as that used in each case. The optical density (darkening) of the film badges when developed was measured by densitometer against that of control films exposed to radiation of known quantity and quality. Chart 1 shows a typical relationship between optical density and exposure dose for a film of the kind used in this survey. By using films of two different sensitivities (Dupont 555 and 606) it was possible to measure doses ranging from 0.5 to 10,000 milliroentgens. The films were found to be reliably reproducible. Error due to increased wave length of scattered radiation and to the varying angles of incidence of this radiation on the film is small enough to be ignored. The values that were obtained by this method are shown in Table 2.

Gonadal irradiation by fluoroscopy was similarly measured, although, as in earlier studies,[4] the estimate of central beam dose was made with an ionization chamber placed on a child-sized Masonite® phantom. The results are shown in Table 3.

The actual exposure dose to the gonads of the children was lower than the skin badges indicated, for radiation of the kind used in routine studies (66 kilovolt peak, half value layer 2.9 mm. aluminum) loses about 25 per cent of its surface intensity at a tissue depth of 1 cm. Thus the actual dose to the gonads of a small boy is probably about 75 per cent of the skin dose. Nevertheless, the values given for "gonad area" are only a measure of exposure on the upper inner anterior thigh; they are probably lower than the gonad dose and probably increase or diminish in the same proportion. In general, the findings in this study suggest a lower gonad dose than was reported by earlier investigators. As was anticipated, the highest central-beam exposures were incurred by fluoroscopy, which resulted in an average skin dose of 5700 milliroentgens per minute. The image intensifier, however, provided good visualization at a rate of only 850 milliroentgens per minute.

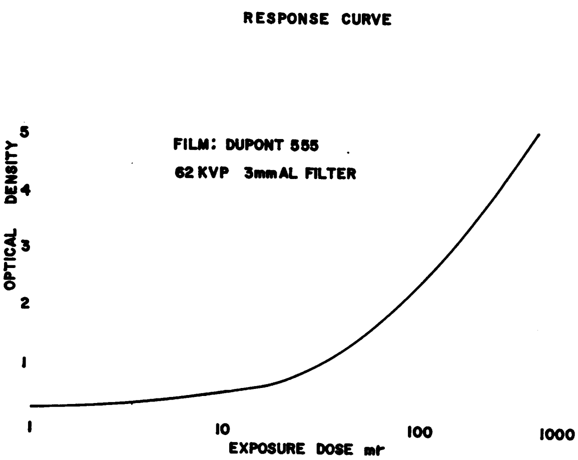

Chart 1.—Relationship between optical density and exposure dose of film badge used in study of gonad area skin dose.

Studies of the hip, the urinary tract and the gastrointestinal tract gave widely varying results (Tables 2 and 3). Some slight doses represented only scatter, while others were so large that the gonad area must have been near the primary beam. It is probable that the larger doses in these cases could have been greatly reduced by proper attention to beam centering, to closer coning or to gonad shielding. These are the types of examination in which careful attention to technical details may reduce the gonad dose by as much as nine tenths without compromising the quality of the roentgenogram. These precautions are of less avail in studies of the lumbar spine and pelvis, which should never be made unnecessarily or repetitiously.

As would be expected, examinations of the chest and of the skull consistently caused little gonad irradiation—slight in comparison with the unavoid-

TABLE 2.—*Radiation Doses with Typical Technical Factors* in Roentgenographic Studies of Children Under 12 Years of Age (University of California at Los Angeles)*

					Skin Dose (milliroentgens)		
						Gonad Area	
	KVP†	MAS†	T.F.D.† Inches	Number of Exposures	Central Beam Average	Average	Range
Chest, posteroanterior	66	6	72	1	8.0	<0.5	<0.5-0.7
Chest, posteroanterior and lateral	66-74	6-13	72	2	23	0.8	0.5-1.3
Heart series	66-74	6-13	72	4	42	2.6	0.7-5.7
Skull	64-74	25	40	4-6	426	1.2	<0.5-3.5
Abdomen, anteroposterior	66	20	40	1	80	36	4.4-95
Intravenous pyelogram	66	20	40	3-7	226	104	3.9-370
Hip	74	25	40	2-3	187	141	6.6-380
Lumbar spine	68-84	20	40	5	2050	40	30-46
Cardioangiography	90	8	33	36	3100	0.7	0.5-0.9

*Filtration: 3 mm. aluminum.
†KVP = Kilovolt peak; MAS = Milliampere seconds; T.F.D. = Target film distance.

TABLE 3.—*Radiation Doses with Typical Technical Factors in Fluoroscopic Studies of Children Under 12 Years of Age (University of California at Los Angeles)*

						Skin Dose (milliroentgens)		
							Gonad Area	
	KVP*	MA*	T.S.D.* Inches	Dose Rate at Skin (mr*/min)	Exposure Time (min.)	Central Beam	Average	Range
Gastrointestinal series	70	3	18	4200	5	21,000	32	2.8-62
Barium enema	70	3	18	5700	5	28,500	127	27-380
Cardiac catheterization	80	1	18	850	10	8,500	5.3	0.5-22

*KVP = Kilovolt peak; MA = Milliamperes; T.S.D. = Target skin distance; mr = Milliroentgens.

ably high doses received in studies of the pelvis and lumbar spine. Only in association with skull studies did the present investigation indicate a higher gonad dose than was noted in previous surveys—possibly because grids were used and because five exposures were made routinely.

As shown in Tables 3 and 4, the gonad area receives a comparatively small dose in cardiac catheterization (although this is a fluoroscopic procedure) and in cardioangiography—possibly because the radiologist is more careful in these procedures. Table 4 shows the difference in gonad doses from heart studies according to body size (age group). In general the larger children required a stronger central beam and therefore received more scatter and more gonad irradiation, but in several cases infants received a stronger gonad dose from the same examinations, as might be expected with a closer central beam causing more scatter and with the greater difficulty of centering and coning for an infant.

TABLE 4.—*Effect of Body Size on Central Beam and Gonad Area Irradiation in Roentgenographic Heart Studies**

	Age		
	0-2 Yrs. (milli-roentgens)	2-7 Yrs. (milli-roentgens)	7-11 Yrs. (milli-roentgens)
Central beam dose	34	41	68
Gonad area dose	1.1	2.9	3.3

*Posteroanterior, lateral, and both oblique views.

TABLE 5.—*Reduction of Gonadal Irradiation in Children Through Use of High-Speed Roentgen Film*

Chest Film, Posteroanterior and Lateral Views	Old Film (milliroentgens)	New Film (milliroentgens)
Central beam dose	26-60	15-29
Gonad area dose	1-3	0.5-1.3

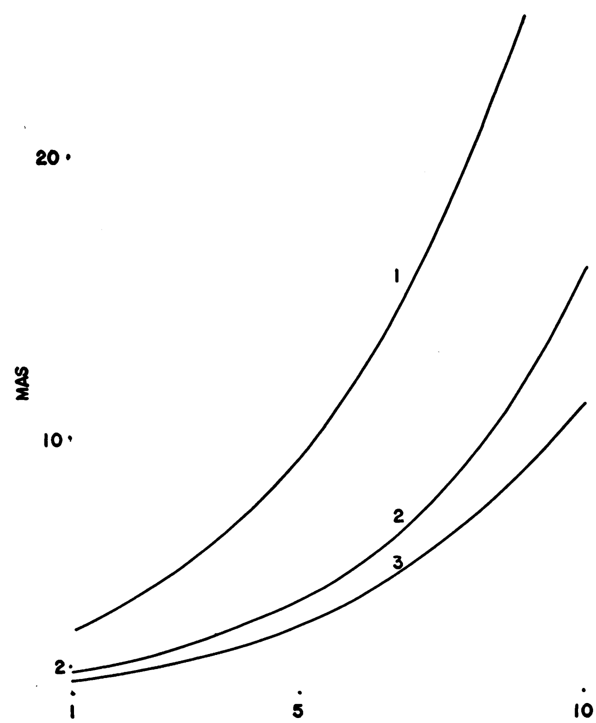

Chart 2.—Exposure in milliampere-seconds (MAS) necessary to produce the same film darkening as the roentgen beam is attenuated by increasing thickness of aluminum is plotted for: 1. "old" film with par-speed screen, 2. "new" film with par-speed screen and, 3. "new" film with high-speed screen. Factors: 66 KVP, 72-inch TFD, 25 ma. Optical density represented by these curves is 0.74.

During this investigation a more sensitive roentgen film giving the same picture after a shorter exposure was put into general use in the radiology department. Comparison of the two films for chest examination of children (Table 5) indicates that the new film permits a reduction of gonad dose by 50 per cent. The difference in film sensitivity is plotted in Chart 2 for different thicknesses of aluminum. At all thicknesses of the standard aluminum wedge, the old film required more than twice as much exposure for the same degree of darkening.

Chart 2 also shows (curve number 3) the decrease in exposure—about 20 per cent—made possible with a high-speed screen.

MEASURES FOR REDUCING GONAD IRRADIATION

A review of gonad dose measurements reported from medical centers throughout the world brings out a wide range of values obtained for each type of examination. Certainly there are a multiplicity of technical factors involved in the reproduction of a given procedure. Nevertheless, the higher doses reported in some studies could have been reduced by adjustment of technique. Indeed, nearly all the investigators who have tried to measure gonad doses have reemphasized techniques by which such doses could be significantly reduced.

As Trout and co-workers,[30] Martin[17] and Ardran[1] have indicated, additional beam filtration effectively reduces skin dose. In examination of the pelvis, for instance, an additional 3 mm. of aluminum reduces the skin dose to less than one-third and the dose to the ovaries to about two-thirds of the unfiltered dose.[31] For this reason the National Committee on Radiation Protection[21] recommends a total filter in the useful beam equal to at least 2.5 mm. of aluminum.

Webster and Merrill[31] noted that when the gonads are outside the direct beam, reduction of cone size (from 20 inches to 12 inches) causes a reduction of more than four-fifths in the ovary exposure dose. The gonad dose due to scatter from the trunk of the body increases by a factor of about three when the central beam is moved 2 inches near the gonads.[31] Attention to cone size and centering can thus result in desirable dose reduction. The continuously variable rectangular diaphragm helps to control beam size. But the shape of a cone is not as important as the area it covers. All roentgenograms of children should be scrupulously delimited, as evidenced by "cone cuts" at the corners of the films.[23]

Higher tube potentials, giving greater penetration, permit a reduction in milliamperes per second with equivalent film exposure; skin dosage is reduced thereby, and in most instances the depth dosage is significantly reduced also.[29] For example, in an anteroposterior view of the pelvis an increase from 70 KVP to 100, with corresponding reduction in current or time, reduces the gonad dose by 50 per cent in the male, 30 per cent in the female.[31]

Lead shielding, where practicable, may also greatly reduce the gonad dose. Testicular shielding, as advocated by Ardran[3] for studies that would expose the testes to the primary beam, can reduce the gonad dose by a factor of 20 or more.

The use of grids significantly increases the required exposure, but they are not generally needed for studies of children.[23]

High-speed intensifying screens permit further reduction of the exposure needed for clear films (Chart 2). Although finer detail can be obtained without the screen this advantage should not often be needed in most cases for studying the smaller bodies of children, and it is often nullified by the child's moving during the longer exposure. The value of these screens and of high-speed film has been discussed above.

Aside from these technical considerations, one of the largest factors in the overall reduction of unnecessary radiation exposure is the *reduction of nondiagnostic and unnecessary radiologic examinations.* This is particularly true of "routine" fluoroscopic examinations which are often useless and always most productive of radiation exposure.[33]

Although Billings and co-workers[4] recently minimized the contribution of fluoroscopy to the total gonad dose, it is now apparent that the largest exposures are incurred through this medium, as many other investigators have testified, with emphasis on the hazard to children.[6,7,16,26] Lefebre and Serra[13] have estimated the skin dose in standard digestive tract studies of children at 70,000 milliroentgens or more, and that for specialized fluoroscopic examination at twice that amount in the central beam. It appears that fluoroscopy of children is rather common and even routine, in some communities, for study of the chest and skeleton in health examinations.[6] A survey by Zavon and Valaer[33] revealed that more than half of the fluoroscopes used by the pediatricians queried had outputs above the maximum of 10,000 milliroentgens per minute recommended by the National Council for Radiation Protection. None of the machines that were examined had filters equal to the recommended 2.5 mm. aluminum. Many of the pediatricians surveyed did not even dark-adapt their eyes before fluoroscopy and most used far higher currents than are necessary in studies of children. These abuses are consistent with the fact that most of the fluoroscopes in use today are in the hands of persons who have had no formal training in radiology. Certainly fluoroscopy should never be used when the same information can be obtained roentgenographically. One minute of fluoroscopy with the beam limited to one-half of the chest area at a skin dose of 10,000 milliroentgens per minute is equivalent, in irradiation, to 600 chest films.

When fluoroscopy of children is necessary, adequate dark adaptation (20 to 30 minutes) permits use of weaker current and thus reduces irradiation. Short exposures of a tenth to five-tenths of a second give as much information as longer ones. Limitation of the field reduces not only the integral dose but also the scatter. Shutters must be liberally used and the aperture should never exceed the size of the observed area. The tube should be at least 15 inches from the table top. When available, image intensifiers should permit a further significant dose reduction, especially if attention is paid to reducing total exposure time. Modern equipment, with well-protected tubes and tables, assures against unsuspected irradiation.

Department of Radiology, University of California at Los Angeles School of Medicine, Los Angeles 24 (Bishop).

REFERENCES

1. Ardran, G. M.: Hazards from increasing use of ionizing radiations: dose to operator and patient in x-ray diagnostic procedures, Brit. J. Radiol., 29:266, 1956.

2. Ardran, G. M., Crooks, H. E.: Gonad radiation dose from diagnostic procedures, Brit. J. Radiol., 30:295, 1957.

3. Ardran, G. M., and Kemp, F. H.: Protection of the male gonads in diagnostic procedures, Brit. J. Radiol., 30: 353, 1957.

4. Billings, H. S., Norman A., and Greenfield, M. A.: Gonad dose during routine roentgenography, Radiology, 69:37, 1957.

5. Brues, A. M.: Somatic effects of radiation, Bull. Atomic Scientists, 14:12, Jan. 1958.

6. Buschke, F., and Parker, H. M.: Possible hazards of repeated fluoroscopes in infants, J. Pediat., 21:524, 1942.

7. Clein, N. W.: How safe is x-ray and fluoroscopy for the patient and the doctor?, J. Pediat., 45:310, 1954.

8. Editorial: Radiation protection during diagnostic studies, Radiology, 57:886, 1951.

9. Hammer-Jacobsen, E.: Gonadedoser i diagnostisk radiologi, Vgesk. f. laeger, 119:279, 1957.

10. Exposure of man to ionizing radiation arising from medical procedures, Report of I.C.R.P. and I.C.R.U. Physics in Med. and Biol., 2:107, 1957.

11. Koren, K., and Maudal, S.: Gonad doses received during the medical application of roentgen radiation, Acta Radiologica, 48:4, 1957.

12. Laughlin, J. S., and Pullman, I.: Biological effects of atomic radiation; gonadal dose produced by medical use of x-rays, Preliminary Report by National Acad. of Sci., Wash., D. C., National Research Council, p. 21, March 1957.

13. Lefebre, J., and Serra, R.: A propos des doses de rayons, X recues par les enfants au cours des examens radiologiques, Arch. Francaises de Pediatrie, 14:1, 1957.

14. Lewis, E. B.: Leukemia and ionizing radiation, Science, 125:965, 1957.

15. Lincoln, T. A.: Gupton, E. D.: Radiation dose to gonads from diagnostic x-ray exposure, J.A.M.A., 166:233, Jan. 1958.

16. Martin, J. H.: Radiation doses to gonads in diagnostic radiology and their relation to long term genetic hazard, M.J. Australia, 2:806, 1955.

17. Martin, J. H.: Radiation doses received by the skin of patient during routine diagnostic x-ray examinations, Brit. J. Radiol., 20:279, 1947.

18. Miller, E. R.: A device for immobilizing children during radiographic examination, Radiology, 58:421, 1952.

19. Miller, R. W.: Some potential hazards in the use of roentgen rays in pediatrics, 11:294, 1953.

20. National Academy of Sciences, Summary Reports: The Biological Effects of Atomic Radiation, National Research Council, Washington, D.C., 1956.

21. Recommendations of the National Committee on Radiation Protection: Handbook 60 of National Bureau of Standards, Dec. 1955.

22. Neel, J. V.: The delayed effects of ionizing radiation, J.A.M.A., 166:908, Feb. 1958.

23. O'Loughlin, B. J., and Ott, T. T.: Improved methods of reducing x-ray exposure in diagnostic studies, Proceedings Annual Technicians Symposium, 1955.

24. Osborn, S. B., and Smith, E. E.: Genetically significant radiation dose from diagnostic use of x-rays in England and Wales: Preliminary survey, Lancet, 1:949, 1956.

25. Robinow, M., and Silverman, N.: Radiation hazards in the field of pediatrics, Pediatrics (Supplements), 20:921, 1957.

26. Sonnenblick, B. P., Levinson, L. J., Furst, N. J., and Koch, J.: The roentgen output of fluoroscopes in routine diagnostic practice quoted by Robinow, 6:31, 1955.

27. Sowby, F. D.: Dose to the gonads during diagnostic procedures, J. Canadian Assoc. of Radiologists, 8:3, 1957.

28. Stanford, R. W., and Vance, J.: Quantity of radiation received by reproductive organs of patients during routine diagnostic x-ray examinations, Brit. J. Radiol., 28: 266, 1955.

29. Trout, E. D., Graves, D. E., and Slausen, D. C.: High kilovoltage radiography, Radiology, 52:669, 1949.

30. Trout, E. D., Kelley, J. P., and Cathey, G. A.: Use of filters to control radiation exposure to patient in diagnostic radiology, Am. J. Roentgenol., 67:946, 1952.

31. Webster, E. W., and Merrill, O. E.: Measurements of gonadal dose in radiographic examinations, N.E.J.M., 257:17, 811, 1957.

32. Yamazaki, J. N., Wright, S. W., and Wright, P. M.: Outcome of pregnancy in women exposed to the atomic bomb in Nagasaki, Am. J. Dis. Child., 87:448, 1954.

33. Zavon, M. R., and Valaer, P. J.: A survey of radiation exposure in pediatric practice, Pediatrics (Supplement), 20:941, 1957.